THE EFFECTS OF DIFFERENT RAP PROPORTION TO THE PERFORMANCES OF COLD IN PLACE RECYCLED MIX

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ABSTRACT

Due to increasing material cost, pavement recycling has become a viable alternative in reducing pavement construction and maintenance cost. Although pavement recycling was first introduced about half a century ago in the west, technology is relatively new in Malaysia. This paper wills analyzes and evaluates how does recycled asphalt pavement (RAP) effects the strength of the recycled pavement structure using bitumen emulsion and cement as the stabilising agent. This paper highlights the mix design procedures and the effects of different RAP content to the recycled mixes performance. The modified Marshall Test procedure was adopted in this study to identify the mix design parameter for the recycled mixes at various RAP content. Four (4) aggregate combinations with various RAP contents which are 0%, 25% and 50% and 75% will be used in this study. The optimum moisture content, bitumen emulsion content and cement content will was determined at every RAP contents in recycled mixes. From the analysis, it will come out with the mix design for each RAP proportion in the recycled mixes. It discusses, on the use of laboratory strength parameters such as Marshall Stability, indirect tensile strength and resilient modulus to determine the optimum binder content of recycled samples. At the end of the study, it will show that the different RAP content in recycled mixes will effect the performance of the pavement.

1. INTRODUCTION

Background

The total extend of Malaysia roads network is approximately 72,781.35 kilometers of pave road and 18,838.25 kilometers of unpaved roads and its about 35.7 % of the network is Federal Truck road and the other 64.3% was state road [1]. Malaysia is relatively a small country of 13 states, which are linked by about 71,000 kilometres of paved roads [1]. A desire to maintain a safe, efficient and cost effective roadway system has led to a significant increase in demand to rehabilitate the existing pavement. Malaysia was adopting the various type of pavement rehabilitation such as overlay, mill and pave, reconstruction, recycling etc. The method was required an import and export old and new material from

the site. The problems that always faced by this type of rehabilitation was the distance of source material from the site was identified that effect the time of construction.

The recycling technique will offer the better logistic which is reduce the haul in aggregate or haul out old material for disposal. Reuse of recycled asphalt pavement in the full-depth recycling (FDR) process is a cost-effective and environmentally responsible method of asphalt pavement reconstruction. The technique of reused the old materials was cold in place recycling (CIPR). FDR was referred to the use of existing pavement material from asphaltic layer until the partial of base materials. Recycled pavements would offer considerable saving in the initial construction cost. It is also proof that the functional and structural performance of the pavement recycling are satisfactory and better than that of the conventionally rehabilitated pavements [2]. The Cold-In-Place Recycling (CIPR) technique was first introduced in Malaysia around the mid 80's. Since then, the concept of recycling road pavements as an alternative rehabilitation measure has become popular and acceptable. The technique involves recycling of all the asphalt pavement section and a portion of the underlying materials with an addition of stabilizing agents to produce a stabilized base course. One of the advantages of the CIPR is cost savings of up to 40 percent over conventional techniques [3].

This study will concentrates on the selection of RAP and non asphaltic material mixes combination to produce the good quality of recycled mix layer which might help the designer to identify the initial combination of RAP and non asphaltic material in the first place. The recycled approach also might show the economic way to ensure that the road still maintained without any environmental effect.

Objectives

The objective of this paper is to highlight the effects of different RAP content to the recycled mixes performances. This paper wills analyzes and evaluates how RAP contents effects the strength of the recycled pavement structure. From the analysis, it will come out with the mix design for each RAP proportion in the recycled mixes.

2. RESEARCH BRIEF

Full Depth Reclaimed (FDR) is a technique where all the asphalt pavement section and a portion of the underlying materials are processed together to produce a stabilized base course. The materials are recycled and additives are introduced; materials are then shaped and compacted before asphalt surfacing (ACBC and ACWC) is applied. Over the past 30 years, great success has been achieved by South African road engineers with the technique of adding small quantities of bitumen emulsion to gravels of fair to good quality [4].

An important aspect of concern to the implementation of full depth recycling is the effect of recycling asphalt pavement and granular base proportion on recycled pavement strength. Variation in the proportion of RAP and granular base material is possible because asphalt layer thickness in existing road varies according to their design or maintenance history.

There are also studies that indicate the performance of RAP in pavement recycling. Bruce carried out a research on cold in place recycling on 1.5 miles long road section using fly ash and bitumen emulsion. It was found that the structural number for fly ash stabilized section was 8.6% higher than resurface treatment layer [5].

Cooley et. al believed that 50% at the optimum RAP content for use in the FDR process and the addition of RAP enhances the structural value of the recycled layer [6].

3. METHODOLOGY

Research Approach

This study approach mainly involves experimental work. The study focuses on the performance of recycled pavement with different combinations of RAP and crushed stone aggregates.

The overall experimental procedure of this research work is shown in the Figure 1. The experimental process was started by obtained the RAP and crushed stone aggregatess from site. The RAP materials were taken from milled old pavement section that was under rehabilitation while as the crushed stone aggregates was taken from a quarry.

The aggregate was tested for the physical properties of materials that recommended by Malaysia Specification for Cold in Place Recycling [7]. The reclaimed asphalt pavement and crushed stone aggregates was tested for Aggregate Crushing Value, Aggregate Impact Value and Flat and Elongated Particles. The material testing was carried out to identified the material properties of both RAP and crushed stone aggregates.

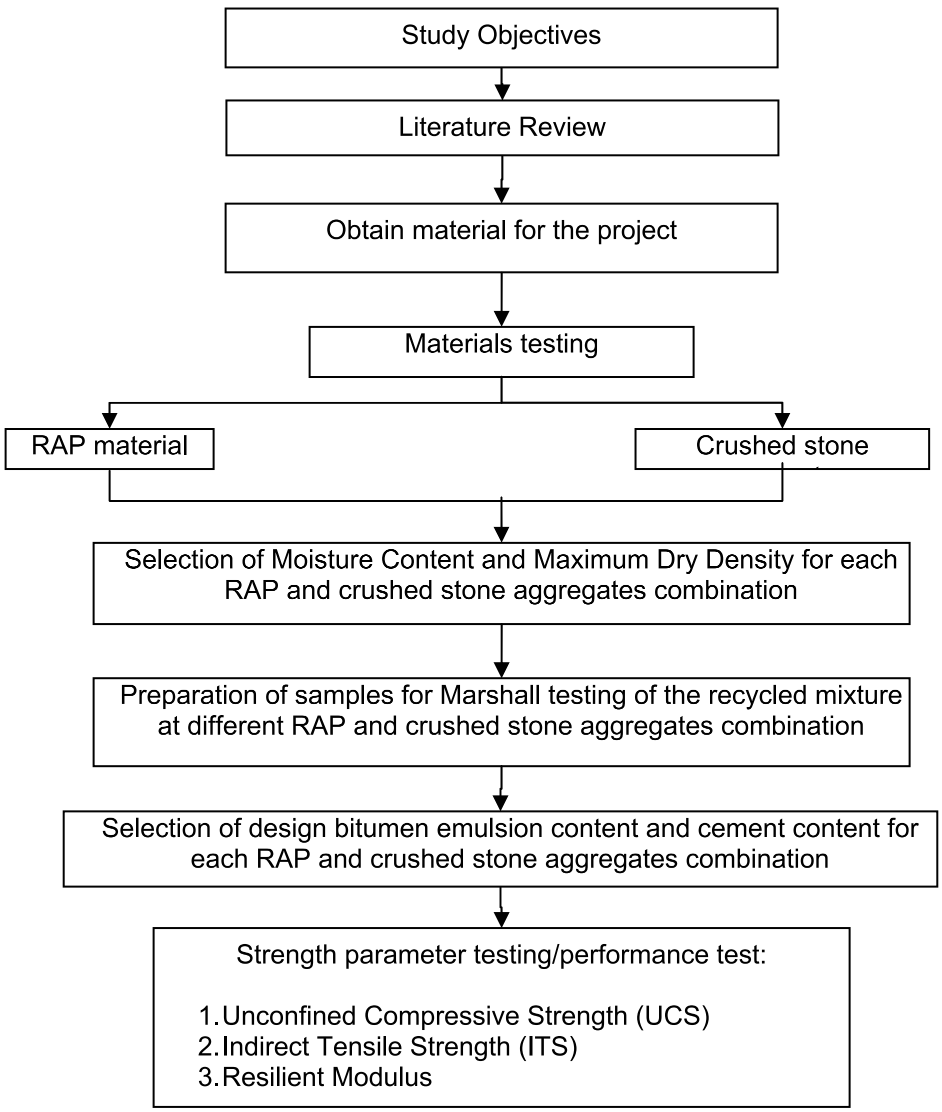

Figure 1: Flow chart for the research approach

Mix Design Procedures

The main objectives of the mix design in this study are to establish the optimum combination of RAP and crushed stone aggregates or granular material to produce the recycled layer. It is also to investigate the suitable grading of the combined material, its optimum moisture content, optimum bitumen emulsion content, required cement content and the strength of the both combination of RAP and aggregate.

This study approach mainly involves experimental work. The study focuses on the performance of recycled pavement with different combinations of RAP and crushed stone aggregatess. The overall experimental procedure of this research work is shown in the Figure 2. The experimental process was started by obtained the RAP and crushed stone aggregatess from site. The RAP materials were taken from milled old pavement section that was under rehabilitation while as the crushed stone aggregates was taken from a quarry.

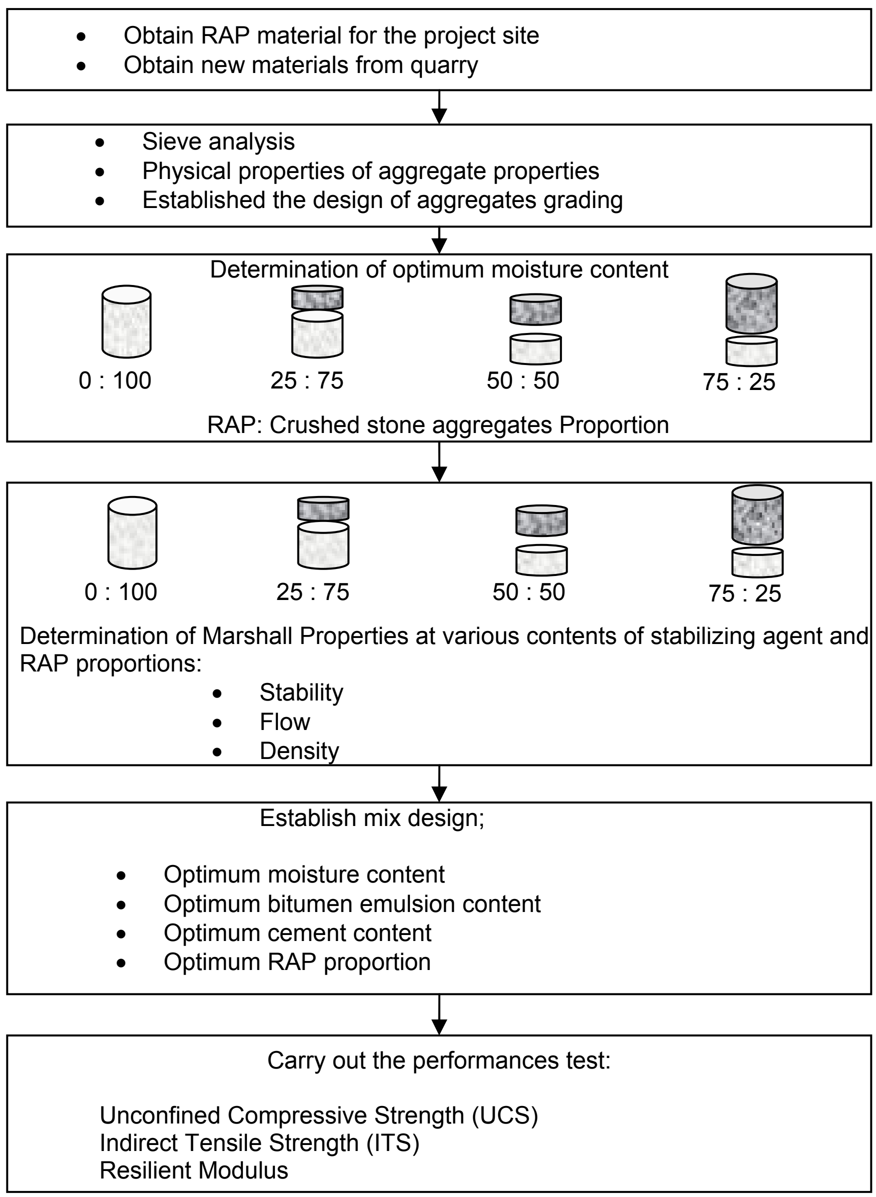

Figure 2: Flow chart for the mix design procedure

The aggregate was tested for the physical properties of materials that recommended by REAM Specification for Cold in Place Recycling [7]. The reclaimed asphalt pavement and crushed stone aggregates was tested for Aggregate Crushing Value, Aggregate Impact Value and Flat and Elongated Particles.

Both the RAP and crushed stone aggregates were sieved and stocked separately according to each single size. One grading line which complies with Malaysia Cold in Place Recycling Specification has been selected for this experiment. The selected grading line was taken from the centre of the specification grading envelope. The proposed grading was combinations of RAP and crushed stone aggregates in the ratios of 0:100, 25:75, 50: 50 and 75: 25 respectively. The ratio is simplified as 0:100 for 0% RAP, 25:75 for 25% RAP, 50:50 for 50% RAP, and 75:25 for 75% RAP. The RAP materials and crushed stone aggregates was combined at various RAP proportions at one selected grading.

The Proctor test was conducted using the combinations of RAP and crushed stone aggregates at every RAP proportions to identify the optimum moisture content. The purpose of doing Proctor Test is to determining the optimum fluid content (OFC) and maximum dry density (OMC) of the recycled mixes at 0%, 25%, 50% and 75% RAP content. The OMC for each RAP proportion was adapt to the next step of determination of optimum bitumen emulsion and cement content using Marshall Method.

The next step was preparation of Marshall samples for each RAP and aggregate combination at OMC from the results of Proctor Test according to Modified Marshall test. Each RAP and crushed stone aggregates combinations were prepared for the Marshall sample at bitumen emulsion content range from 2% to 6% by weight in increments of 1% at every stage of cement content of 0%, 1.5%, 2.0% and 2.5%. The samples were compact using Marshall compactor with 75 blow per face.

The samples then were tested for Marshall Stability, Density and flow test for determination of the optimum bitumen emulsion and cement content of the recycled mixes at every RAP contents. The result of maximum stability and density vs. bitumen emulsion content was plotted. The data was analyzed and the optimum of bitumen emulsion and cement content of each RAP contents was identified. The optimum bitumen emulsion content for the varies recycled mixes without cement was taken as the arithmetic mean of the bitumen emulsion content at maximum Stability and maximum density.

At the final stage, the specimens for the compacted recycled mix then to be prepared at optimum moisture content, optimum bitumen emulsion and cement content for every RAP proportion. The specimens then to be tested for the Indirect Tensile Strength (ITS) soak and unsoak and Unconfined Compressive Strength (UCS) to identify the recycled mix performance at different RAP content.

Description of Materials

The RAP was sieve to identify the existing grading. The result showed in Figure 3 show that the existing RAP grading was not fall within the Malaysia Cold in Place Recycling Specification grading limit especially for the fine aggregate. The amount of fine aggregate in RAP was less especially for aggregate size 0.075 and below. So that, generally it can say that the RAP samples have more courser particles and lesser fine particles.

The design grading was selected using Malaysia Cold in Place Recycling Specification grading limit. The design grading was exactly taken from the middle of Malaysia Cold in Place Recycling Specification grading envelope. So that, an existing RAP grading need to be modified to be as designed grading by adding the crushed stone aggregates into the existing RAP sample. The combinations of bitumen emulsion and cement were used as a recycling agent in this study. It also will highlight the effect of the recycling without the present of cement at various RAP proportion.

The samples then were prepared using the selected grading at different RAP content, bitumen emulsion content and cement content.

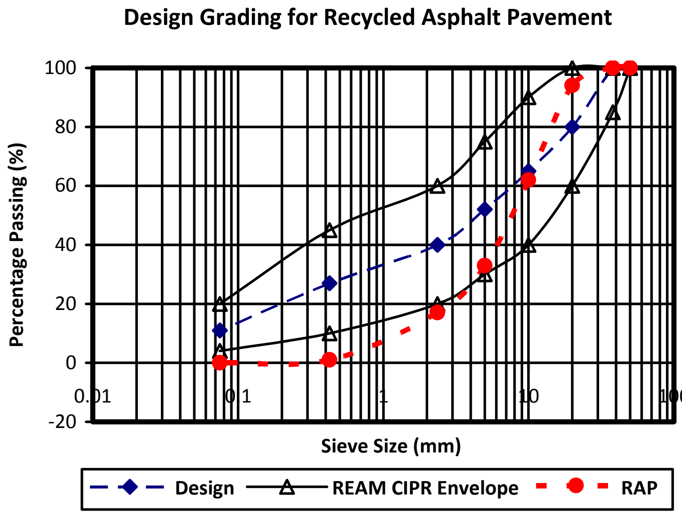

Figure 3: The gradation that shows gradations of design grading and existing RAP compared to REAM CIPR specification grading limit [7]

The specific mix design parameters in Malaysia REAM CIPR Specification are showed as Table 1 below (REAM) [7].

Table 1 : Specified Design Parameter

Stabilising Agent	Requirements on test parameter			
	ITS	ITS (Soaked)	UCS	Tensile Strength Retained
Foamed /Bitumen Emulsion	≥ 0.2 MPa	≥ 0.15 MPa	≥ 0.7 MPa	≥ 97%

4. RESULT AND ANALYSIS

Material testing

The result of Aggregate Impact Value, Aggregate Crushing Value and Flakiness Index showed in Table 2 are within the Malaysia CIPR specification requirement.

Table 2 : The material properties for the RAP and crushed stone aggregates samples

Parameter	**Crushed stone aggregates**	**RAP**	**JKR Specification Limit REAM [7]**
Aggregate Impact Value	25.6	21.8	< 30
Aggregate Crushing Value	22.17	15.38	<30
Flakiness Index	16.91	16.69	<30

Moisture Content

The ranges of optimum moisture content are 5.2% to 6.5% while the ranges of dry density are 1.885 to 2.260kg/m^3. The highest optimum moisture content and maximum dry density was 6.5% and 2.260kg/m^3 respectively had been achieved at the control sample which is 0%RAP content if there is no cement using in the recycled mixes. The moisture content was reduced as the increasing of RAP content in recycled

mixes. It is showed that, the existing RAP contained moisture and the water content must be control during the construction. Tables 3 and Figure 4 below present the optimum moisture contents and maximum dry density result of each RAP proportion in recycled mixes. The result also showed that the increasing of RAP will reduces the optimum moisture content and maximum dry density in the recycled mixes.

Table 3 : The result of Proctor Test

RAP Content (%)	Optimum Moisture Content (%)	Maximum Dry Density (kg/m^3)
0%	6.5	2.260
25%	6.0	2.220
50%	5.2	2.099
75%	5.1	1.885

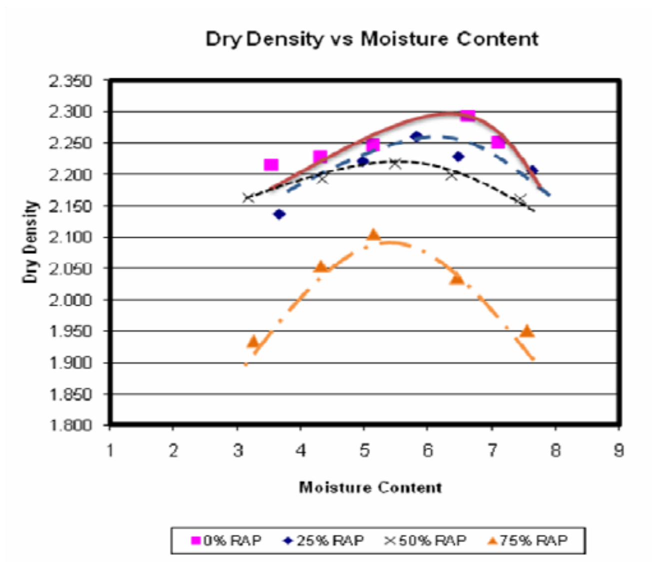

Figure 4: The result of the optimum moisture content and Maximum Dry Density for each RAP combination

Marshall testing

The result of Marshall Stability testing was showed in Figure 5. The result showed the Marshall Stability of 0%RAP samples was maximum at 46kN when 1.5% cement and 2.5% bitumen emulsion was added into the mixes. The maximum Marshall Stability result of 25%RAP and 50%RAP was same which is about 51kN with 2.5%cement content.

The result also showed the Marshall Stability of 75%RAP in the recycled mixes has the lowest Marshall Stability. The range of Marshall Stability for 75% RAP was 24 to 27 kN. The Marshall Stability of the recycled mixes that contained 75%RAP also does not showed any significant different when cement included in the mixes. This is showed that the cement does not contribute to the strength properties for the recycled mix with higher RAP content or there also can say that the cement does not work effectively with the RAP that contained high bitumen content.

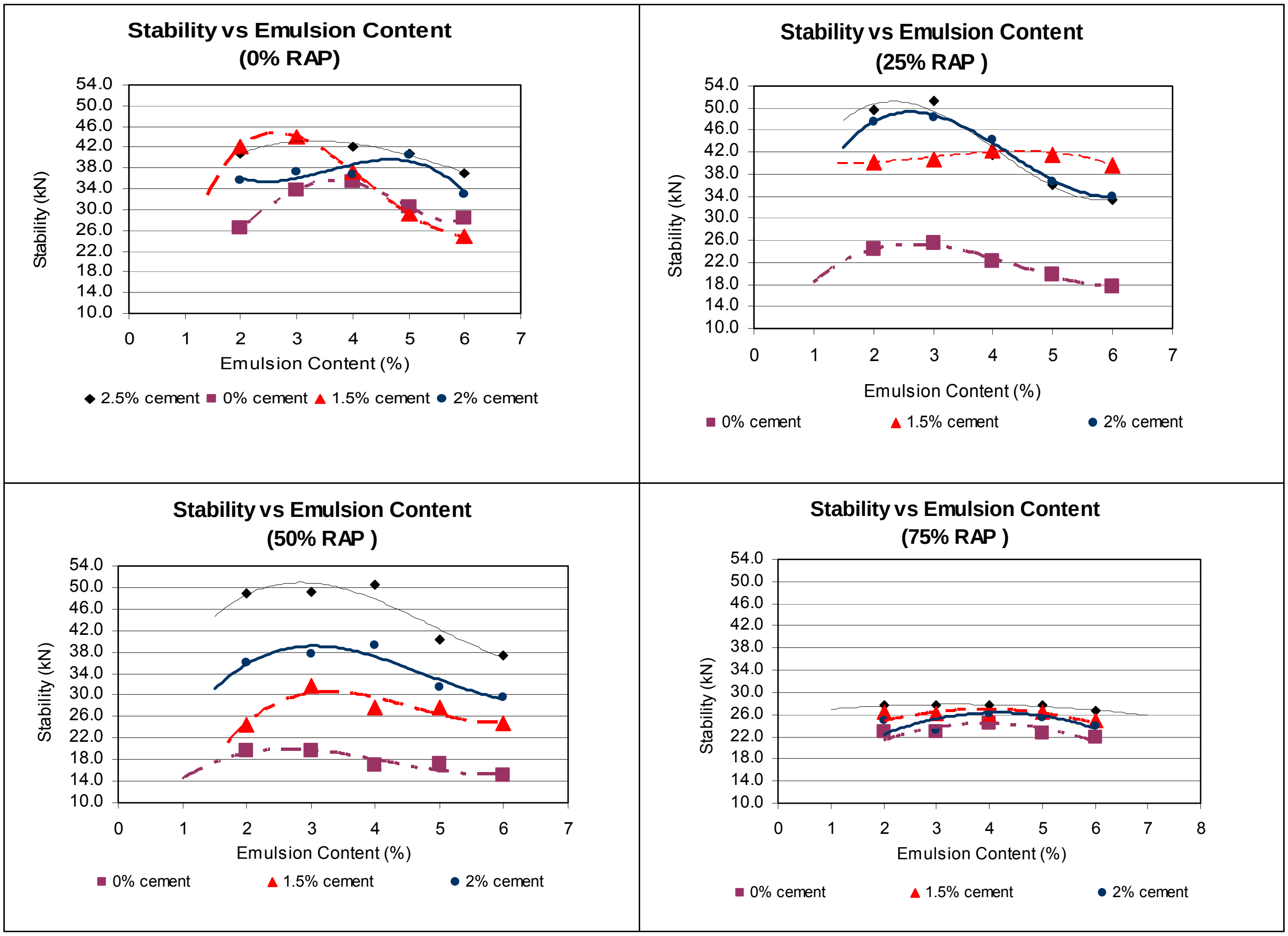

Figure 5: Result of Marshall Stability for recycled mixes at various RAP proportion

Density

At same cement content, the density of the recycled mixes was reduced when the RAP contents in the recycled mixes increased. The results of density for the recycled mixed are showed as the Figure 6. The additional of cement into the mixes significantly effect the maximum density of the mixes without RAP but not the recycled mixes. It was found that the density of the mixes increased as the increasing of cement content in the recycled mixes. It was different for the recycled mixed with 75%RAP which it found that there are no significant effects when the cement content was added in the recycled mixes.

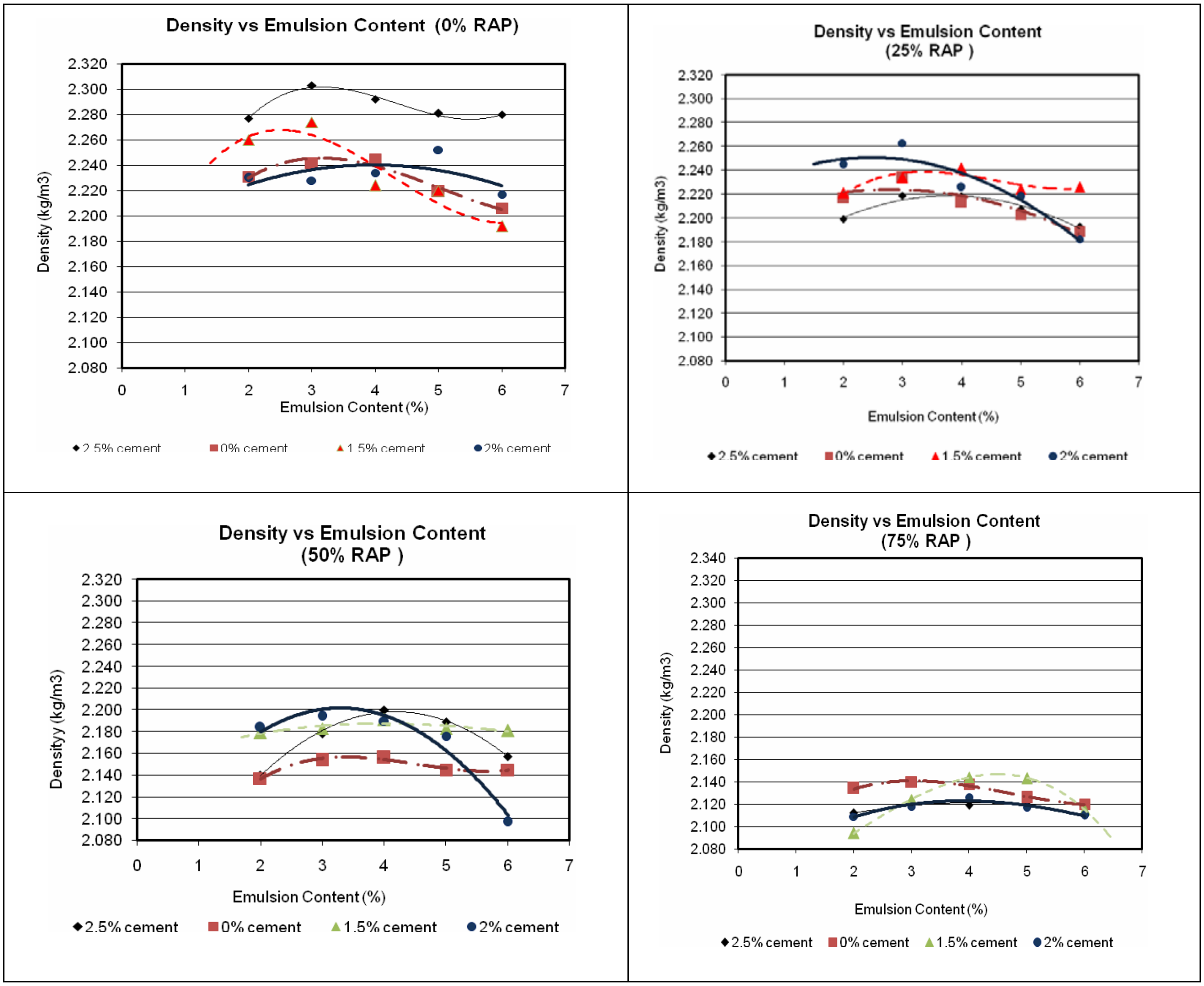

Figure 6: Result of Density for recycled mixes at various RAP proportion

Marshall Flow

The result of Marshall Flow was showed in the Figure 7. It was showed that the introduce of cement into the mix without RAP and 75%RAP content resulted the higher Marshall Flow than the recycled mixes with 25%RAP and 50%RAP. The result also found that the Marshall Flow does not show the significant differ when the cement content in the recycled mixes at same RAP content increased. The range of Marshall Flow rate of the recycled mixes with cement was 2.0 – 5.5 mm.

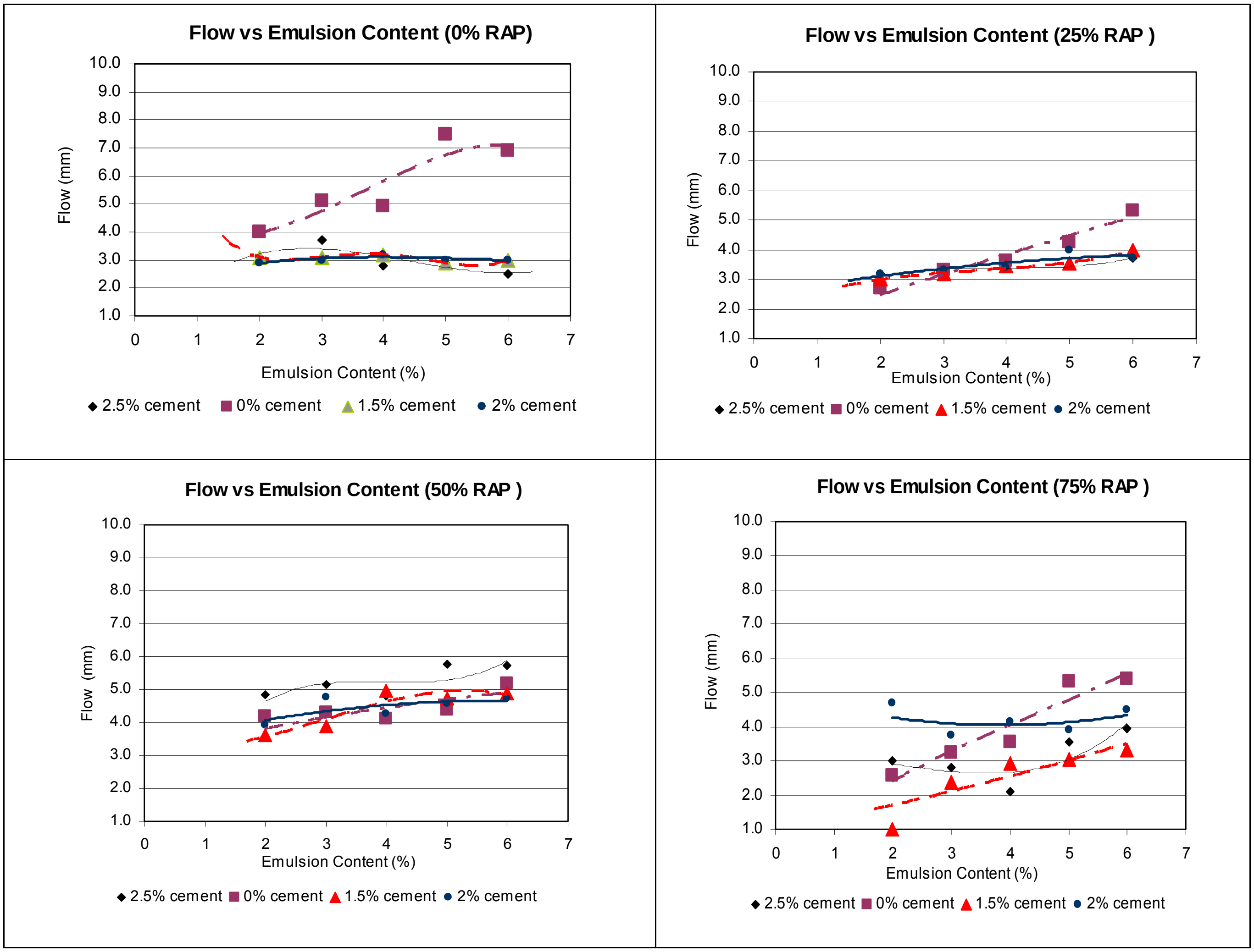

Figure 7: Result of Marshall Flow for recycled mixes at various RAP proportion

Mix design Selection

The result in Table 4 showed the mix design for each recycled mixes with various RAP content. The result found that the used of 25%RAP in the recycled mixed required only the minimum bitumen emulsion content but contribute to the good performance. The combination of 3.0% bitumen emulsion and 2.0% cement is needed to get the highest Stability with 25%RAP in the recycled mixes.
From the result it is also showed can be recommend that the optimum RAP content that can be used for pavement recycling that can give the highest strength was 25%RAP.

Table 4: the mix design selection criteria

RAP content	Cement Content (%)	Stability (kN)	Optimum Moisture Content (%)	Optimum bitumen emulsion content (%)
0%	1.5	44	6.5	2.5
25%	2.0	49	6.0	3.0
50%	2.0	40	5.3	3.5
75%	1.5	27	5.1	4.0

Indirect Tensile Strength

The samples were prepared at mix design properties at every RAP proportion to observed the performance of design samples at certain strength and had been tested for several performance test which are Indirect Tensile Strength (ITS), Unconfined Compressive Strength (UCS) test and Resilient Modulus test. The result showed that the ITS value were increased as increasing of RAP content. The requirement of ITS 0.2 N/mm2 in Malaysia Cold in Place Recycling Specification was achieved at the selected mixes design at every RAP contents. It is also showed in the Table 5 that the maximum ITS values for soak and unsoak for 25%RAP and 50%RAP samples were not much differ. The result also showed that the percentage ITS retained was below 75% as required in Malaysia Cold in Place Recycling Specification unless for 75%RAP. It was suspected that the bitumen emulsion was very sensitive to the moisture content.

Table 5 : The ITS test result at design bitumen emulsion and cement content

RAP content	Bitumen emulsion content (%)	Cement Content (%)	ITS (MPa)		
			Soak	Unsoak	%Retained
0%	**2.5**	1.5	0.23	0.35	64.8
25%	**3.0**	2.0	0.29	0.52	56.3
50%	**3.5**	2.0	0.31	0.50	62.4
75%	**4.0**	1.5	0.16	0.18	88.4

The Table 6 showed the result of UCS testing to the recycled samples. The result showed that the highest UCS was achieved at 25% RAP and dropped when the RAP content increased to 50%. Overall, the required UCS 0.7 N/mm^2 was achieved at the selected mixes design for every RAP content.

Table 6: The UCS test result at design bitumen emulsion and cement content

RAP Content	Compression (N/mm2)	Compression (N/mm2) (Average)
0% RAP	2.05 2.28	2.17
25% RAP	2.51 3.03	2.77
50% RAP	2.42 2.15	2.29
75% RAP	2.18 2.3	2.24

Table 7 showed the result of Resilient Modulus testing using the recycled samples at design mix. The result showed that it was resulting the highest resilient modulus at the mixes without RAP. The introducing of RAP in the mixes was reduced the resilient modulus of the recycled mixes.

Table 7: The result of Resilient Modulus at design mixes for recycled mixes

(%)RAP Content	Resilient Modulus (Mpa)
0% RAP	13138
25% RAP	11515
50% RAP	11379
75% RAP	9459

5. CONCLUSION AND RECOMMENDATION

From the result of the studies carried out the following can be concluded;

a. The modified Marshall Design method for recycled mixes was suitable and adequate to comply the requirement of the current Malaysia Cold in Place Recycling Specification.
b. The increasing of RAP will reduces the optimum moisture content and maximum dry density in the recycled mixes.
c. The cement does not contribute to the strength properties for the recycled mix with higher RAP content or there also can say that the cement does not work effectively with the RAP that contained high bitumen content.
d. The result of Indirect Tensile Strength (ITS) for 25%RAP and 50%RAP showed similar result. The ITS value at this RAP proportion was the highest compared to the other RAP proportion but the UCS result showed that 50%RAP proportion in the recycled mixes was obviously increase the UCS to the maximum value. So that, from this study, it was recommend that the optimum RAP proportion than can be used in the recycled mixes was 50%
e. It was found that the bitumen emulsion was sensitive to the moisture.
f. The performances of recycled mixes at mix design meet the minimum requirement as per Malaysia Cold in Place Recycling Specification.

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